there was additional activity. Only in Oklahoma did WirelessCo face a withdrawal penalty as a result of the large double jumps. In two of the markets (Pittsburgh and Des Moines), it paid one bid increment less than the other winner. WirelessCo's double jumps were probably unsuccessful. The message they sent was confusing and led to significant overbidding in Oklahoma.

Although jump bids were rare, there were a few instances where markets closed after a jump bid. For example, PrimeCo's final bid in Chicago was a jump $11.7 million above the minimum bid. WirelessCo dropped out in response. It is impossible to know whether PrimeCo left money on the table or whether the jump induced WirelessCo to drop out.

Strategic shifts or drops can be used to facilitate collusion. In a strategic shift, a bidder shifts to another license to keep prices in other markets from escalating. If firms X and Y are competing in market 1 and firm X is in market 2, then Y switches out of market 1 and into market 2, implicitly telling X to drop 2 to prevent further competition in market 1. In a strategic drop, a bidder drops a license, prompting a reciprocal drop from a competitor. If X and Y are competing in markets 1 and 2, then Y drops market 1, implicitly telling X to drop market 2. Strategic shifts and drops have two difficulties, which limit their use. First, the implicit message is much less clear than with a gift withdrawal or code bidding. Second, strategic shifts and drops are only effective once the competition is down to two bidders. Prices at this point may already be high. There is little evidence that strategic shifts or drops were used successfully to limit competition.

In special circumstances, raising one's own bid may be a good strategy. If the high bidder believes that the remaining competitor would be willing to bid up one bid increment, but not two, then the high bidder may benefit from raising its own bid. PrimeCo successfully anticipated GTE's final bid in Jacksonville. PrimeCo raised its own bid in round 108, topping GTE's final bid in the same round. A good example of the cost of such a strategy is Powertel's $2.5 million raise of its own bid in Jacksonville in round 110. Powertel expected GTE to come back in Jacksonville, but GTE had decided to drop the market. Another costly example is WirelessCo's experience in San Francisco. In round 97, WirelessCo, Alaacr, and American Portable were still competing for the remaining San Francisco license (it was assumed that PacTel would win the other). WirelessCo was the high bidder and had just made the gift withdrawals of Tampa and Houston to get American Portable to move off San Francisco. WirelessCo expected Alaacr and perhaps American Portable to come back in San Francisco. In anticipation of this competition, WirelessCo raised its own bid by $14.4 million. But the competition did not materialize. Both Alaacr and American Portable dropped out of San Francisco.

For the most part, bidders tended to bid on the cheaper of the two bands. However, in several cases this rule was not followed. There are two reasons for bidding on the more expensive license. First, the bidder may prefer one band over the other, because it expects to win neighboring licenses of the same band. AT&T attempted to get band A in most of its markets; PrimeCo favored band B. Second, it may make sense to bid against the weaker bidder to avoid punishment in other markets. A bid against the strong firm may upset tacit collusion and drive prices higher. In four markets, the final bid was on the more expensive license against a smaller (weaker) bidder. AT&T bumped PCS America in Buffalo rather than the slightly cheaper license held by WirelessCo. In Detroit, WirelessCo bumped American Portable,

rather than AT&T although it was $1 million more. In Atlanta, AT&T bumped Powertel, not GTE although it was $4.3 million more. In Minneapolis, WirelessCo bumped Continental although it was $1.3 million more than American Portable. One possible explanation for this behavior is that the bidder was concerned with retaliation in other markets. Otherwise, bidding against the strong bidder is the better strategy. It saves money and raises the cost of a strong competitor.

Strategic bidding played a more important role in the MTA auction than in the narrowband auctions, because of the reduced competition. However, even in this auction, much of the strategic bidding did not seem to improve the bidder's position. Subtle signaling was especially ineffective.

5.7 Bid Withdrawals

Bid withdrawals are another example of strategic bidding. The purpose of allowing withdrawals is to let bidders back out of failed aggregations. There were 21 withdrawals in the auction. All but two were in stage 3. However, none of the withdrawals seems to be motivated by an exit from a failed aggregation. Rather the withdrawals appeared to be for some other strategic purpose.

There are several reasons for withdrawing a bid:

- To back out of a failed aggregation. The withdrawal follows being bumped on complementary licenses. The bidder either drops eligibility or shifts to another set of complementary licenses.
- To increase flexibility in the next round of bidding. A bidder with little free eligibility might want to shift among licenses in the next round.
- To maintain eligibility or raise rivals' costs. A bidder might engage in a fight for a license it is not truly interested in. It then withdraws when the competitor drops out.
- To maintain eligibility without raising prices. A bidder withdraws from a license and then places a minimum bid. When repeated, this maintains eligibility, but prices do not rise, so long as a competitor places the minimum bid. The withdrawal signals to others that the bidder is not truly interested in the license.
- To make room for another bidder to drop down. In a fight with another bidder, a bidder might withdraw to suggest that the competitor move to the withdrawn license rather than continue the fight. This facilitates tacit collusion by offering a gift and then lowering the cost of punishment. It is easier to punish bad behavior by the bidder that takes over a withdrawn license. A raise by the bidder that withdrew is essentially costless, since the withdrawn bid amount is already committed.

Table 6 shows the 21 bid withdrawals in the auction. WirelessCo made 11 of the 21 withdrawals. Only 6 withdrawals resulted in penalties. The $14.836 million in penalties were paid by WirelessCo ($14.514 million) and American Portable ($0.322 million). Most of the withdrawals were to maintain eligibility (11 of 21) or increase flexibility (5 of 21). WirelessCo's extensive double bidding resulted in only two withdrawals (Minneapolis and Oklahoma) with penalties of $3.851 million. None of the withdrawals appeared to be caused by predatory bidding (bidding up a license to raise a rival's costs).

One pair of withdrawals was apparently intended as a gift to entice a competitor to shift to the withdrawn licenses. In round 97, WirelessCo withdrew from Tampa and Houston, hoping that American

Portable would take this gift and move off San Francisco. American Portable accepted the gift, moving down to Tampa and Houston in the next round. WirelessCo's gift cost it $8.505 million in penalties, but this is less than one bid increment in San Francisco.

A possible implication of the withdrawals in stage 3 is that some licenses might go unsold. Late in stage 3, bidders might not have the eligibility to pick up withdrawn licenses. Fortunately this did not happen. Most of the withdrawals near the end of the auction were to increase flexibility in the next round. If the licenses were not picked up by a competitor, then the withdrawing bidder picked up its own withdrawals.

6 The C-Block Auction

The next auction was for the third (and final) 30 MHz block of broadband spectrum, the C-block. 493 BTA licenses were sold to small businesses (annual revenues less than $40 million). Large firms were not eligible to bid. Although this auction was to start shortly after the MTA auction finished, the auction was delayed for 6 months in the courts.[12] The C-block auction finally began on December 18, 1995, and concluded nearly 5 months later on May 6, 1996, after 184 rounds. Revenues net of the 25% bidding credit were $10.2 billion, more than double the prices in the MTA auction.

Figure 4 displays the bidding activity and revenue by round. Bidding activity was much higher than in the MTA auction — so much so that the stage transitions were hardly noticeable. Bidders did not hold back as they did in the MTA auction. Prices quickly escalated to well beyond MTA prices. Early activity was especially strong in the major markets. This is consistent with the major markets (e.g., Chicago) being key to a synergistic combination in a broader area (the midwest). Bidders wanted to resolve the major markets before going after the smaller complementary markets. Bidding in the second half of the auction was almost exclusively on these smaller markets.

---

[12]On March 15, 1995, the U.S. Court of Appeals in the District of Columbia stayed the auction until the court could hear the case brought by Telephone Electronics Corporation (TEC), a rural telephone company. TEC claimed that it was unfairly excluded from the auction and questioned the constitutionality of bidder preferences for women and minorities. In early April, TEC withdrew its lawsuit in a settlement with a third-party. PCS PrimeCo, a major bidder in the MTA auction, agreed to give TEC what it wanted. The auction, which was scheduled to begin in June 1995, was postponed until early August. The auction was postponed again when the June 12 Supreme Court decision in *Adarand v. Pena* made it likely that the race and sex preferences would not survive a constitutional challenge. The FCC modified the rules to give all small businesses, regardless of race or sex, the same 25% price preference and attractive payment terms. Previously, only women or minority controlled firms were eligible for the most attractive terms. The auction was rescheduled to August 29. The C-block auction was stayed a third time on October 18, in response to Radiofone's challenge of the PCS/cellular cross-ownership rule, which limits the amount of broadband PCS spectrum that a cellular licensee can acquire in its cellular market. On October 25, Justice Stevens, Circuit Justice for the Sixth Circuit, vacated the stay. On October 30, the full U.S. Supreme Court declined to overturn Justice Stevens' Order dissolving the Sixth Circuit stay.

Many were shocked by the high prices. What accounted for average net prices of $39.88 per pop in the C-block, compared with $15.54 per pop in the MTA auction? There are two main explanations: installment payments and competition.

The small bidders in the C-block auction were given attractive payment terms to compensate for difficulties in raising capital. C-block winners pay 5% at the end of the auction, 5% at the time of award, and then ten years of installment payments at the 10-year Treasury note rate. The quarterly installments cover interest only for the first six years. During the auction the 10-year T-note rate was about 6.5%. If we assume a cost of capital for the firm of 14%, then this 7.5% spread amounts to an additional bidding credit of 32%. With a 16.5% cost of capital (10% spread), the installment payments give an additional bidding credit of 40%. Hence, the C-block price of $39.88 becomes $.6 \cdot 39.88 = \$23.93$.

This calculation ignores the option value created by the back-loaded installment plan. To the extent that there is uncertainty about the value of spectrum, the option of default in case spectrum has a low value makes a license worth more than its expected value. Nonetheless, an effective bidding credit from installments in the range of 30 to 50 percent seems about right. At 40%, the installment payments account for about $16 of the $24 spread between the C and A-B prices.

The second important factor explaining the higher prices was the much greater competition in the C-block. Competition in the MTA auction was weak in several of the major markets. In contrast, competition in the C-block auction was strong in all markets. The eligibility ratio (total eligibility in pops divided by total pops being auctioned) was 6.75, compared with 1.93 in the MTA auction. There were 255 bidders compared to 30 in the MTA. 89 bidders won licenses, rather than 18 in the MTA.

Ausubel and Cramton (1996) demonstrate that larger bidders have a greater incentive to reduce demand in order to keep prices low. Hence, having a large number of small bidders is more competitive than a small number of large bidders, holding the eligibility ratio fixed. Moreover, competition may have been heightened by the fact that in many cases the bidders were startups that would be out of a job if licenses were not won.

The importance of competition in determining prices is seen by comparing prices in the four largest MTAs (Table 7). The C-block prices have been discounted by 40% to account for the installment payments. Notice that the C-block prices are fairly close. In contrast, the Chicago MTA price is well above the other MTA prices. In Chicago, all three nationwide bidders (WirelessCo, AT&T, and PrimeCo) were eligible to bid; whereas, in New York and San Francisco, only WirelessCo was eligible. This lack of competition in New York and San Francisco seems the only compelling explanation for the low prices in these markets, relative to Chicago. Judging from these markets, the discounted C-block prices are not out of line with the prices on the more competitive markets in the MTA auction. This conclusion is supported by the price regression in Ausubel, et al (1996). The strongest determinant of prices in the MTA auction was the level of competition, measured as the eligibility in the market over the total eligibility. In the C-block auction this variable was insignificant, since all markets were competitive.

Table 7. Price Comparison in Major Markets ($ per person in 1994)

Market	C-block price with 40% installment discount	MTA price
New York	27.74	16.52
Los Angeles	26.47	24.05
Chicago	27.18	30.40
San Francisco	31.54	16.10

The high C-block prices raised the concern that some winners may default. Indeed, the fourth largest winner (BDPCS) failed to make the initial 5% down payment, defaulting on 17 licenses for which it bid $874 million. BDPCS was expecting the down payment to come from US West, but apparently US West changed its mind about funding BDPCS. The FCC quickly decided to reauction the licenses. The reauction began on July 3. By the fifth day of bidding (round 16), net revenues of the reauctioned C-block licenses already matched the $874 million total from the default. On day six, the auction was nearly over with two consecutive rounds with no new bids (the auction remained open, because at least one firm submitted a proactive waiver). In all but a few markets, the reauctioned licenses sold for close to the BDPCS prices.

Aside from this default, which was quickly corrected, the auction was successful. There surely will be future defaults, given the large number of small businesses that won licenses. However, this must be expected in an auction involving such substantial sums and yet small upfront payments.

This auction demonstrated the feasibility of conducting simultaneous multiple-round auctions with hundreds of licenses and hundreds of bidders. Although the auction was long, the long duration gave bidders and capital markets time to make difficult decisions that determined the assignment. The speed of the reauction indicates the importance of price uncertainty in determining auction duration.

7 Auctioning Encumbered Licenses

Two other auctions were conducted at the same time as the C-block auction. The MDS (wireless cable) auction had the same structure as the C-block: a single license in each of 493 BTAs. In the SMR auction, 20 licenses were sold in each of 51 MTAs (1020 licenses in total). Both of these auctions involved the sale of heavily encumbered licenses. The FCC had previously awarded numerous MDS and SMR licenses of limited geographic scope. In these auctions, winners must protect incumbents against interference. Hence, what was sold was like swiss cheese with large holes in some of the most desirable areas. As a result, MTA and BTA populations were no longer a relevant measure of the size of a license. Instead, the FCC used "bidding units," which were an attempt to measure the size of the effective population covered by a license.

Both auctions attracted a large number of bidders (155 for MDS and 128 for SMR), but the initial eligibility ratios (3.6 for MDS and 2.4 for SMR) were well below that of the C-block. Figures 5 and 6 show the bidding activity and revenue by round. The stage transitions are noticeable in both, suggesting a mild tendency for the bidders to hold back. However, neither had the large swings in activity found in the MTA auction.

The discontinuous jump in revenues in round 9 of the SMR auction was the result of a mistaken bid. Atlanta Trunking intended to bid $125,025, but added three extra zeros, and submitted the bid of $125,025,000. Atlanta Trunking immediately withdrew the bid, but according to the FCC rules was liable for a withdrawal penalty well in excess of $100 million. This was the first mistaken bid in FCC spectrum auctions, but not the last. Three mistaken bids were placed in the C-block auction. MAP added an extra zero to its bid in round 10. Then only two rounds later, PCS 2000 made the same mistake on a larger license. Finally, in round 38, Georgia Independent added an extra zero as well. Given that over 60,000 bids were placed in these three auctions, it is not surprising that a few mistakes were made. The FCC responded to these mistaken bids by modifying the software to warn the bidder if a bid appears to be a mistake. In addition, they adopted a rule for mistaken bids. The rule limits the size of the penalty in the event of a mistaken bid, but still imposes a penalty sufficient to discourage mistakes.

In the SMR auction, the incumbents expressed concern that they might be at a disadvantage in the auction. They argued that they were vulnerable to speculators, to predatory bidding, and would have less flexibility in stage 3 to move to unencumbered licenses. I was of the opinion that incumbents were at an advantage. The incumbent would be buying areas that complement its existing licenses; whereas, the nonincumbent would be buying swiss cheese with substantial interference problems. As it turned out, incumbents paid significantly less than nonincumbents.

8 Assessing the Auction Design

Since we do not observe the values firms place on licenses, it is impossible to directly assess the efficiency of these auctions. Nonetheless, we can indirectly evaluate the auction design from the observed behavior. To aid in comparing and assessing the auctions, Table 8 presents summary statistics for each auction. These statistics are discussed throughout this section.

8.1 Extensive Information was Revealed by the Bidding

Two essential features of the design are (1) the use of multiple rounds, rather than a single sealed bid, and (2) simultaneous, rather than sequential sales. The goal of both of these features is to reveal information and then give the bidders the flexibility to respond to the information. This should reduce the winner's curse and more importantly facilitate efficient aggregations. Proponents of sequential auctions have argued that the information revealed in a simultaneous auction is of little help to the bidders, because it is only preliminary information. The final outcome may be far from the current state, even near the auction's end. Using the data from the auctions, I evaluate both the quality of the information revealed in the auction and the ability of firms to respond to the information. There are two

dimensions to the information: the assignment of licenses and the prices of the licenses. Each is considered in turn.

As observed earlier, the upfront payment is an excellent indicator of the quantity of spectrum won. It, however, tells us nothing about which licenses a firm will win. For this bidders must look at the bids during the auction. In each of the auctions, much about the final assignment was determined well before the auction's end.

In the nationwide auction, the high bidders in round 28 were the same as in the final assignment 19 rounds later, except for one license. Only a few questions remained, such as which firms would get the two 50s. Well before round 28, it was clear who was likely to win the 50/50s and 50/12s. The assignment in the regional auction settled even more quickly. By round 10, the high bidders were the same as in the final assignment 95 rounds later.

One might expect that the MTA auction would present a different picture, because of the rampant under bidding in stages 1 and 2 of the auction. However, despite this under bidding, the current assignment revealed a great deal of information about the final assignment. Figure 7 tracks by round the fraction of current high bidders (pop weighted) that eventually win in their current markets. This fraction, which hits 50% in the second round, gradually increases throughout the auction. At the end of stage 2 (round 64), 76% of the current high bidders were still high at the end of the auction (round 112). The major exceptions were in New York, Chicago, and Washington.

The clarity of the assignments stems from the fact that most bidders had focused interests. They bid on a relatively small set of licenses throughout the auction, although they were typically eligible to bid on much more. As a result, the number of active bidders in each market was small. Table 9 shows the distribution of the number of excess bidders in each market. It is based on the number of bidders that were active in the market after stage 2. A typical market had 3 excess bidders (5 bidders in total) over the entire auction. By the end of stage 2, there was only a single excess bidder in a typical market.

Table 9. Distribution of Excess Bidders in Markets (Population Weighted)

Number of excess bidders in market	0	1	2	3	4	5
Percent of markets over entire auction	0	13	20	41	20	6
Percent of markets after stage 2	15	42	30	11	1	0

The current bids provide good information about final assignments, but what about prices? Again, in all six auctions, current prices give good information about relative prices at end of auction. Figure 8 displays the correlation between current and final prices throughout the MTA auction. Initial bids are only modestly correlated with final prices (30%). This correlation does not increase until stage 2, but then increases sharply in the early rounds of stage 2, reaching 62% by round 21. From round 21, the correlation increases steadily throughout the remainder of the auction. The correlation is 83% at the end of stage 2.

The remaining question is whether bidders have the flexibility to act on the information. By the time firms have a good sense about prices and the assignment, they may not have sufficient eligibility to respond. Clearly this was not the case in the narrowband auctions. In the nationwide auction, firms maintained their full eligibility throughout the auction, since the auction never moved out of stage 1. In the regional auction, the assignment and prices settled early. Bidders had good information about the outcome throughout stage 2 and had plenty of flexibility to shift among licenses.

The biggest concern about flexibility came in the MTA auction, where much of the action did not occur until stage 3. Figure 9 shows the eligibility ratio by round. Starting at 1.93, the eligibility ratio fell to 1.53 by the end of stage 2. Hence, at the end of stage 2, there is good information about prices (83% correlation with final prices) and assignments (76% eventually win), and yet plenty of eligibility (1.53) to shift among licenses in response to this information. This flexibility was observed in the firms' behavior through most of stage 3. Firms bidding on several licenses were able to move among different sets of licenses, only losing an insignificant amount of eligibility. American Portable and others made such shifts in several rounds. The fact that there was much movement among licenses as prices changed suggests that the simultaneous design was important in determining the outcome.

The extensive information about prices and assignments is not simply a result of markets closing early. Figure 10 shows the fraction of licenses by round with final bids (pop weighted). At the end of stage 2 only 19% of the licenses had received final bids. By round 74, the correlation between current and final prices was up to 89%, even though final bids had been received on only 25% of the licenses. A great deal of bidding was still to take place, but the information about the eventual outcome was excellent.

8.2 Similar Items Sold for Similar Prices

An advantage of the simultaneous ascending-bid design is that it tends to generate market prices. Similar items should sell for similar prices. There is strong evidence of this in all six auctions. In the nationwide auction, the price differences among similar licenses were at most a few percent and often zero. In the regional auction, price differences were larger, but still small with the exception of one license with a bid withdrawal late in stage 3. The importance of forming nationwide aggregations within the same band was probably the source of the larger differences in prices. In the MTA auction, only the A and B licenses within the same market are directly comparable. A and B prices differed by less than one bid increment in 42 of the 48 markets. In the six markets where prices differed by more than an increment, three involved withdrawals (two to maintain eligibility and one gift) and three were to avoid strong bidders, which was especially important if the strong bidder favors one band.

The generation of market prices is important from an efficiency viewpoint. In addition, it contributes to a sense among the bidders (and observers) that the auction is fair. Most bidders in all six auctions walked away feeling satisfied by the process, even if they were disappointed by the outcome.

The simultaneous stopping rule is an important factor in achieving market prices and efficiency. Market-by-market closing would not give the bidders sufficient flexibility. With market-by-market closing, the auction is essentially a sequential auction with endogenous order. A license may close by the

time a bidder wants to shift to it. This possibility was seen in each of the auctions. It was common for licenses to have no bids for several rounds followed by steep increases in price. For example, in the nationwide auction, bids on the 50/50s stopped for seven rounds (from round 20 to 26) at $70 million, but then increased to $80 million. Prices on the 50/12s had to increase before bidding could continue on the 50/50s. This tendency for long pauses in activity in particular markets was even more pronounced in the MTA auction.

8.3 Efficient Aggregations were Formed

Valuations depend on the set of licenses won. Hence, it is important to use an auction form that allows bidders to express these value interdependencies. Such a design would encourage the formation of efficient aggregations. Supporters of the simultaneous ascending-bid design argued that bidders would have sufficient flexibility to express valuations for combinations of licenses, even without package bids. However, others argued that package bids would be essential to achieving efficiency. They feared the exposure problem would discourage bidders from going after synergistic gains. Evidence from the auctions suggests that bidders were able to form efficient aggregations without package bids.

In the nationwide auction, the aggregation problem was simple. Bidders acquiring multiple bands preferred adjacent bands. In all cases, bidders acquiring multiple bands were successful in winning adjacent bands (PageNet won bands 1 and 2, and McCaw won bands 3 and 4).

In the regional auction, the aggregation problem was more complicated. Several bidders had nationwide interests. These bidders would have to aggregate all five regions, preferably all in the same band. The bidders were remarkably successful in achieving these aggregations. Four of the six bands sold as nationwide aggregations. Bidders were able to win all five regions within the same band. Even in the two bands that were not sold as nationwide aggregations, bidders winning multiple licenses won geographically adjacent licenses within the same band. The regional auction demonstrated that in this setting it is possible to build large aggregations without allowing package bids.

Large aggregations also were formed in the MTA auction. Overall, there was a tendency for bidders to win the same band when acquiring adjacent licenses. AT&T was high bidder on the A band in its top markets and PrimeCo was the high bidder on the B band in its top markets. The large aggregations won by WirelessCo, AT&T, and PrimeCo appear to have efficient geographic coverage when one includes cellular holdings. WirelessCo won nationwide coverage except for a single strip of licenses from Cleveland to Tampa and a few other holes (most notably Chicago). PrimeCo won nationwide coverage except for a single block of licenses in the central U.S. Likewise, AT&T was able to fill its cellular holes except for three regions. The absence of package bids did not seem to prevent firms from forming efficient aggregations. However, it is certainly possible that efficiency was reduced, because of under bidding. High-value bidders may have dropped out of markets too soon to keep prices on other markets from escalating.

Further evidence of efficient aggregations comes from the absence of bid withdrawals. There were no withdrawals in the nationwide auction. The two withdrawals in the regional auction were minor. They were caused by strategic bidding unrelated to a bidder backing out of a failed aggregation.

Withdrawals in the MTA auction did not suggest aggregation failures. The withdrawals through stage 2 were of no importance. There was an increase in withdrawals in stage 3, but they were mostly motivated from efforts to maintain eligibility, rather than by aggregation failures. A few were attempts to end competition in other markets. If successful, such attempts might reduce efficiency, but they only succeeded in one case. No withdrawals were to back out of failed aggregations. Exposure, then, did not seem to be a problem preventing efficient aggregations.

The C-block auction had 50 withdrawals out of nearly 30,000 bids. Most of these occurred early in the auction. Intouch, for example, made 12 withdrawals in the first 10 rounds, apparently for some signaling purpose. There were no withdrawals in the last 55 rounds of bidding.

Certainly there are settings in which the exposure problem is severe and efficiency is destroyed by not allowing package bids. Experimental evidence is given in Bykowsky, et al. (1995). These tend to be settings with extreme synergies, where a missing piece makes the collection worthless. Real estate projects and room on the space shuttle have this character. However, the synergies in PCS licenses are much less severe. MTA licenses are sufficiently large to capture much of the regional synergies. There is some benefit to having adjacent licenses and there may be other marketing or network synergies, but they are not 0-1. Those favoring package bids may have overestimated the extent of the exposure problem.

Ausubel, et al. (1996) analyze the MTA auction data to see if there is evidence that synergies caused bidders to pay more for adjacent licenses. They find no such evidence, which suggests that the exposure problem probably did not hamper the formation of efficient aggregations.

8.4 Tacit Collusion was Limited

The simultaneous multiple-round auction gives bidders a great deal of information and provides enormous flexibility in responding to this information. In a competitive auction, this information and flexibility should improve efficiency, but it also opens to the door to more collusive strategies. Is there any evidence of collusion in the early PCS auctions? There are two main concerns: limiting competition through alliances, followed by tacit collusion during the auction.

There was no evidence of collusion in either the nationwide or regional auctions. Alliances were unimportant in the nationwide auction. The successful firms bid on their own. In the regional auction, alliances were formed between designated entities and established paging companies. The alliances transformed weak bidders into strong companies capable of competing with the industry leaders. Bidding was aggressive and competitive throughout both narrowband auctions. Marginal bidders dropped out only after long fights with the eventual winners. Jump bidding, although pervasive, seemed ineffective at steering competitors to other licenses. Prices were higher than many predicted. Even when excess demand was small, bidders were unwilling to scale-back demands in order to close the auction at substantially lower prices.

Collusion was much more of an issue in the MTA auction. The PrimeCo alliance presented the biggest problem. It transformed four deep-pocketed bidders with extensive market eligibility into one deep-pocketed bidder with limited market eligibility. It created the possibility of slight competition in

some major markets, such as New York and Los Angeles, and reduced competition in other markets. In contrast, the WirelessCo alliance probably increased competition by creating a strong nationwide bidder from companies that would have been much weaker on their own.

The PrimeCo alliance greatly increased the chances of successful tacit collusion. This is the primary explanation for the rampant under bidding in the early stages of the MTA auction. Given the possibility that the matching could occur at low prices, there was no incentive for firms to bid aggressively. The low activity requirement in stages 1 and 2 meant that bidders could bid well under their true demands and yet preserve most or all of their eligibility. As such, firms tended to limit their bids to what they wanted most.

Fortunately, tacit collusion is easily upset. It requires that all the bidders reach an implicit agreement about who should get what. With thirty diverse bidders unable to communicate about strategy except through their bids, forming such a unanimous agreement is difficult at best. Although some bidders had clear interests in a few licenses, other bidders like Alaacr and American Portable simply were looking for value. These value-seeking bidders can have large demands at low prices and are hard to punish. In addition, the nationwide goals of WirelessCo, AT&T, and PrimeCo were incompatible. Not all three could succeed in forming a nationwide aggregation. How much should each cut back to allow room for the other two, as well as the smaller bidders? Disagreements were bound to arise and these disagreements would limit tacit collusion.

Fears of collusion peaked in round 10 of stage 1 when bidding activity plunged to just a single bid in Detroit despite bargain prices. But with the onset of stage 2, bidding activity jumped back up and remained strong. Bidders refused to cut eligibility until well into stage 2. Sorting out who should get what was not going to be accomplished without the price mechanism. Nonetheless, it was clear that stage 3 would be needed to push prices up. By round 60, activity had once again dropped below 10%. Many bidders could maintain eligibility in stage 2 by simply sitting on their high bids.

Strong bidding early in stage 3, especially by WirelessCo and AT&T, put fears of tacit collusion to rest. These firms needed to cut eligibility significantly for the auction to close and neither expressed any interest in doing so. The auction did not end until the average price surpassed government estimates. In a 1992 study, the Congressional Budget Office estimated prices to be between $3.50 and $15.00 per pop. In 1994, the Office of Management and Budget estimated a price of $12.47 per pop compared with the actual average price of $15.54 per pop. Estimates based on recent cellular transactions would be much higher, but it is difficult to unbundle the license value from the value of the network and existing customers.

Narrowband prices ($3.10 per MHz-pop in the nationwide auction and $3.46 in the regional auction) were about six times higher than broadband prices ($.52 per MHz-pop). However, this is not evidence of collusion in the MTA auction. The narrowband and broadband prices are not comparable, since it would be difficult to use broadband spectrum for narrowband applications. The imbalance simply reflects the different supply and demand conditions in the two markets. It does suggest that the FCC should go ahead with its plans to allocate more narrowband spectrum.

Although tacit collusion failed overall, there may have been some markets where bidders dropped out early to improve the outcome in other markets. For example, American Portable decided to drop out of San Francisco in response to WirelessCo's withdrawal in Tampa and Houston. However, WirelessCo raised its own bid in San Francisco in the round that American Portable dropped down to Tampa and Houston, so this "tacit collusion" was far from perfect. In addition, WirelessCo rebid in Houston later in the auction, bumping American Portable. After a careful review of the bidding, I was unable to find any clear cases of successful tacit collusion.

In those markets that appear to be especially good values (New York, Los Angeles, and San Francisco come to mind), the critical feature seems to be an absence of deep-pocketed bidders. My assessment is that the PrimeCo alliance had more to do with these good values than the success of tacit collusion.

The auction outcome might have been radically different without the value-seeking bidders, especially Craig McCaw and American Portable. There was close to too little competition in the MTA auction. It is in precisely such circumstances that the simultaneous multiple-round auction is most vulnerable to collusion. In future auctions, it may make sense to reduce collusion risk by limiting alliances among major players in the industry. Such restrictions are common. For example, the top oil companies are not allowed to partner in oil lease auctions. However, it is not at all clear what rule the FCC could have adopted to prevent the PrimeCo alliance and yet encourage synergistic alliances. Formulating general rules would be complex if not impossible. Preventing such alliances on a case-by-case basis would likely delay the auctions and lead to litigation.

8.5 The Auction Durations were Reasonable

An important advantage of auctions is their ability to quickly assign licenses to high value uses. The sooner licenses are assigned, the sooner companies can provide services demanded by consumers. Hence, in judging the auction design, we must consider how long it takes to conduct the auction.

Certainly the narrowband auctions were concluded in a timely manner. The nationwide auction took one week and the regional auction concluded in two weeks. Other auction designs could assign the licenses more quickly, but given the importance of the licenses to the firms involved, a more hasty process would be foolish. Companies needed time to think through their options. The short auction durations were possible in these auctions, because of the small number of licenses up for auction (10 in the nationwide and 30 in the regional) and the relatively low stakes. This meant that many rounds could be conducted in a day. Toward the end of the auctions, when bidding activity was low and few decisions were being made, more than one round occurred each hour.

The MTA broadband auction concluded after about three months. This may seem like a long time, but given the magnitude of the decisions involved three months is a modest duration. The speed of the auction was limited by the large number of licenses (99) and the very high stakes. The auction can only go as fast as the bidder that needs the most time. WirelessCo's bidding was especially complex, because of the large number of licenses it was interested in. WirelessCo urged the FCC not to do more than two

rounds per day. It was hard not to listen to WirelessCo's plea, since it was the largest bidder and had a legitimate concern.

Probably the largest cost of the three month duration is in postponing subsequent auctions. The remaining broadband auctions cannot begin until after the MTA auction. Companies need to know the MTA outcome before forming alliances and attracting investors. However, the cost associated with a three month delay is probably minimal. Companies also need time to develop plans and get capital in line.

The final three auctions, with many more bidders and licenses, took about four months, 180 rounds, and 80 days to complete. All three auctions had long final tails that involved few bids and little change in revenue or assignment. The FCC did well to shorten this tail by conducting many rounds per day. By the end, 8 or more rounds per day were held in each auction.

Certainly compared with prior methods of assignment the auctions have been successful. Even with streamlined comparative hearings, it took the FCC an average of two years to award thirty "non-wireline" cellular licenses (licenses not limited to local telephone companies). After the FCC switched to lotteries in cellular service, the average time to award a non-wireline license decreased to about one year. With auctions, the average time to award licenses has been less than a year. Of the ten nationwide narrowband PCS licenses, seven were awarded in under two months and the remaining three in under five months. The thirty regional narrowband PCS licenses were awarded in approximately three months. The 99 MTA broadband PCS licenses took three months and the licenses were awarded in four months from the close of the auction. It should be noted that the length of an auction depends in part on policy decisions and that faster is not always better. In the case of the MTA broadband auction, most of the auction was conducted with two rounds per day so that bidders would have sufficient time to evaluate the results of the previous round and plan their bidding strategy.

8.6 Minimum Bid Increments were Needed

Minimum bid increments play an important role in controlling the pace of the auction. If set too high, the increments choke off bidding, even when the high bidder does not have the highest value. If set too low, the auction may last too many rounds if bidders bid at the minimum level. Large increments are especially useful early in the auction when activity is high and prices are low. There is little cost to large increments early in the auction. Large increments are inefficient only when they prevent the highest valuer from placing a bid. But if prices are low, the highest valuer can easily top the high bid by the minimum increment. Inefficiencies only appear when a license is about to close and the size of the inefficiency is at most one bid increment. (Markets do not literally close license-by-license. Individual licenses "close" in the sense that there are no further bids in the market.) Thus, the auctioneer can start with a large increment and then reduce the increment as the probability of closure increases. In the nationwide auction, where all of the licenses were good substitutes, overall bid activity was an excellent measure of when licenses were about to close, so a sensible rule tied the bid increment to bid activity.

In the MTA auction, licenses in different markets are not good substitutes and there is much greater variation in prices across markets. The FCC had no way to know when markets were likely to close. Also with so many licenses, it made sense to have a single rule for setting increments across all licenses. In

the standard rule, the minimum increment is the greater of a percentage increment or a per-pop increment. Initially, the percentage increment was 5% and the per-pop increment was $.60 per pop (or $.02 per MHz-pop). In this case, until the price reaches $12 per pop, the per-pop increment would bind. Before a license receives a bid, the minimum increment is 0. This prevents licenses worth less than $.60 per pop from going unsold.

Early in stage 2, bidders continued to bid at the minimum level, but eligibility did not drop. Hence, to speed the auction along, the percentage increment was doubled to 10% in round 31. By round 31, the 10% increment was greater than the per pop increment in many important markets. The fact that the percentage increment was 5% at the beginning of the auction was largely irrelevant, since early in the auction it is the per pop increment that is binding. The per-pop increment remained $.60 per pop. The rationale for leaving the per-pop increment fixed was that several of the low-priced licenses might be near closure and this would reduce any inefficiencies on these licenses.

At the end of stage 2, the percentage increment had been cut back to 5%. When stage 3 began with the same strong activity seen in the beginning of stage 2, the FCC considered whether to raise the percentage increment to 10% again. This option was rejected and with good reason. In stage 3, activity drops as bidders reduce eligibility by permanently dropping out of markets. It is precisely at this point — the point when reservation prices are reached — that a modest bid increment is desired. Markets closed throughout the remainder of stage 3. This is seen in Figure 10, which shows the fraction of licenses (pop weighted) with final bids by round. Licenses did not begin to close until midway through stage 2 (about round 36). By the end of stage 2 (round 64) only 19% of the licenses had received their final bids. The remaining 81% of the licenses closed throughout stage 3 at a rapid and steady pace. Hence it was important to keep the bid increment low throughout stage 3.

Based on similar reasoning, there is little point in dropping the bid increment late in stage 3. Toward the end of the auction, the vast majority of markets have already effectively closed and there is no way for a bidder to return to a market to take advantage of a lower increment. The lower increment then is only effective in the few markets that have yet to close. Since there is no way to predict when reservation prices may be reached in these markets, dropping the increment to 2% might greatly extend the auction (as was the case in the regional auction). The efficiency and revenue gain is likely small, since the low increment only applies to the few markets that have yet to close. Hence, it made sense to keep the increment at 5% throughout stage 3.

In retrospect, the MTA auction could have been sped up without much efficiency loss by adopting larger bid increments in the early rounds. Increments of 10% or $1.20 per pop in the first thirty rounds would have shortened the auction by more than a week. These adjustments were made for the final three auctions.

In future auctions, the FCC plans to further quicken the pace by using even larger bid increments early on. A difficulty with large increments is that some licenses may be close to final prices when others are far from final prices. To avoid this problem, the FCC plans to use license specific increments, where activity is used as an indicator that the license is far from the final price and a larger increment is in

order. In the C-block it was not uncommon for some licenses to have no new bids and for others to have a dozen.

8.7 The Activity Rule Worked Well

One potential problem with the MTA broadband auction was the fact that prices and assignments shifted substantially in stage 3. Ideally, most of the action would take place in stage 1 and stage 2, when the less restrictive activity requirements were in place. Bidders in the early stages have great flexibility in shifting among licenses. In stage 3, flexibility is curtailed, increasing the possibility of inefficient assignments.

Perhaps surprisingly, the stringent stage 3 activity requirement did not pose a major obstacle to large bidders. Bidders were able to maintain eligibility through double bidding. Even without the double bid, firms bidding on several licenses were able to move among different sets of licenses, only losing an insignificant amount of eligibility. However, stage 3 does distort behavior. In each round, firms placed strategic bids to maintain eligibility and withdrawals were more common. Nonetheless, it does not appear that this strategic bidding severely reduced efficiency.

In stage 3, it is possible for the auction to effectively become a sequence of auctions from largest market to smallest as bidders drop down to smaller licenses. Bidders may not have the flexibility to make more sophisticated shifts. This hypothesis can be tested by looking at the time of final bids by license during stage 3. There was a slight tendency for larger licenses to close earlier. However, the association is weaker when one restricts attention to stage 3. Both the bidding behavior and the time of closure by license suggest that bidders had much more flexibility in stage 3 than in a sequence of auctions from largest to smallest.

The problems of a long stage 3 in the MTA auction were reduced in the last three auctions by adjusting the activity rule. In the C-block, the required activity in stage 1 was increased from 33% to 60% and the activity in stage 2 from 67% to 80%. This forces more of the sorting to occur in stages 1 and 2, and yet still give the bidders substantial flexibility in these early stages. In addition, the FCC reduced the stage 3 activity requirement from 100% to 95%, increasing flexibility in stage 3. Similar, activity requirements were used in the MDS and SMR auctions.

A further problem with a low activity requirement is that it can increase the possibility of successful tacit collusion. With an activity requirement of 1/3, bidders can make modest demands without incurring the cost of a loss in eligibility. Unilateral cooperative reductions in demand are possible without losing the ability to punish if reciprocal reductions are not made by others. With a 100% activity requirement, modest demands are only possible with a loss of eligibility.

9 Conclusion

The FCC made a bold decision in settling on the simultaneous multiple-round auction to award the PCS licenses. Although this auction form had theoretical virtues, it was unproven. The easy decision would have been to adopt a traditional design, such as a sequential oral auction. Instead, the FCC chose

to innovate. After careful study, the FCC began testing and fine-tuning the design with the auction of nationwide and regional narrowband licenses. These first two auctions proved remarkably successful. The theoretical virtues of the design became practical realities. Bidders moved easily among license combinations as prices adjusted. This movement was unhampered by activity requirements in the nationwide auction and only slightly constrained in the regional auction. There was a strong tendency for prices of similar licenses to sell for similar prices. Finally, the license assignments satisfied technical efficiency. When bidders won multiple bands, the bands were adjacent; when bidders won multiple regions, the regions were adjacent and on the same band.

Armed with these early successes, the FCC pushed forward with the MTA broadband PCS auction, the largest auction ever. Although this auction did not share the early aggressive behavior seen in the narrowband auctions, revenues increased steadily throughout the auction. Despite a restrictive activity requirement in the final stage, bidders managed to shift among licenses in response to price changes and build sensible aggregations. Competition heated up in the final stage, suggesting that the auction did identify an efficient allocation through escalating prices. Nonetheless, because of bidder alliances, competition was limited in several markets. Future auctions may benefit from restricting alliances among major firms.

The C-block, MDS, and SMR auctions demonstrated the feasibility of the simultaneous multiple-round auction even with hundreds of bidders and licenses. These auctions required about 80 days of bidding — a relatively short period to determine an assignment of this complexity.

The success of these auctions does not imply that alternative designs would be less successful or that success is assured in future auctions. Although the early evidence is encouraging, there is still much to learn about auctions in this complex setting. One thing is certain: the assignment of licenses by auction is a huge improvement over allocation by lottery or comparative hearings. Market competition is putting the licenses in the hands of those companies best able to use them. Firms, consumers, and taxpayers all benefit.

References

Ashenfelter, Orley (1989), "How Auctions Work for Wine and Art," *Journal of Economic Perspectives*, 3, 23-26.

Ausubel, Lawrence M. and Peter C. Cramton (1996), "Demand Reduction and Inefficiency in Multi-Unit Auctions," Working Paper, University of Maryland.

Ausubel, Lawrence M., Peter Cramton, R. Preston McAfee, and John McMillan (1996), "Synergies in Wireless Telephony: Evidence from the MTA Auction," Working Paper, University of Maryland.

Avery, Christopher (1994), "Strategic Jump Bidding in an English Auction," Working Paper, Kennedy School of Government, Harvard University.

Ayres, Ian and Peter Cramton (1996), "Pursuing Deficit Reduction Through Diversity: A Case Study of How Affirmative Action at the FCC Increased Auction Competition," *Stanford Law Review*, forthcoming.

Ballard, Charles L., John B. Shoven, and John Whalley (1985), "General Equilibrium Computations of the Marginal Welfare Costs of Taxes in the United States," *American Economic Review*, 85, 128-138.

Banks, Jeffrey S., John O. Ledyard, and David P. Porter (1989), "Allocating Uncertain and Unresponsive Resources: An Experimental Approach," *Rand Journal of Economics*, 20, 1-22.

Bykowsky, Mark M., Robert J. Cull, and John O. Ledyard (1995), "Mutually Destructive Bidding: The FCC Auction Design Problem," Working Paper, CalTech.

Chakravorti, Bhaskar, William W. Sharkey, Yossef Spiegel, and Simon Wilkie (1995), "Auctioning the Airwaves: The Contest for Broadband PCS Spectrum," *Journal of Economics and Management Strategy*, 4, 345-373.

Cramton, Peter (1995), "Money Out of Thin Air: The Nationwide Narrowband PCS Auction," *Journal of Economics and Management Strategy*, 4, 267-343.

Engelbrecht-Wiggans, Richard and Charles M. Kahn (1995), "Multi-Unit Auctions with Uniform Prices," Working Paper, University of Illinois.

Federal Communications Commission (1994), *Fifth Report and Order*, FCC 94-178, Washington, DC.

Federal Communications Commission (1994), *Third Report and Order*, FCC 94-98, Washington, DC.

Gandal, Neil (1995), "Sequential Auctions of Interdependent Objects: Israeli Cable Television Licenses," Working Paper, Tel-Aviv University.

Maskin, Eric S. and John G. Riley (1984), "Optimal Auctions with Risk Averse Buyers," *Econometrica*, 52, 1473-1518.

Maskin, Eric and John Riley (1995), "Asymmetric Auctions," Working Paper, UCLA.

Matthews, Steven A. (1983), "Selling to Risk Averse Buyers with Unobservable Tastes," *Journal of Economic Theory*, 30, 370-400.

McAfee, R. Preston and John McMillan (1987), "Auctions and Bidding," *Journal of Economic Literature*, 25, 699-738.

McAfee, R. Preston and John McMillan (1996), "Analyzing the Airwaves Auction," *Journal of Economic Perspectives*, 10, 159-176.

McAfee, R. Preston and Daniel Vincent (1993), "The Declining Price Anomaly," *Journal of Economic Theory*, 60, 191-212.

McMillan, John (1994), "Selling Spectrum Rights," *Journal of Economic Perspectives*, 8, 145-162.

Milgrom, Paul R. (1987), "Auction Theory," in Truman Bewley (ed), *Advances in Economic Theory - Fifth World Congress*, Cambridge, England: Cambridge University Press.

Milgrom, Paul (1995), *Auction Theory for Privatization*, forthcoming, Cambridge, England: Cambridge University Press.

Milgrom, Paul R. and Robert J. Weber (1982), "A Theory of Auctions and Competitive Bidding," *Econometrica*, 50, 1089-1122.

Myerson, Roger B. (1981), "Optimal Auction Design," *Mathematics of Operations Research*, 6, 58-73.

Rothkopf, Michael H. and Ronald M. Harstad (1990), "Reconciling Efficiency Arguments in Taxation and Public Sector Resource Leasing," Working Paper, Rutgers University.

Rothkopf, Michael H., Ronald M. Harstad, and Yuhong Fu (1996), "When Does it Pay for a Bid Taker to Subsidize Inefficient Bidders?" Working Paper, Rutgers University.

Rothkopf, Michael H., Aleksandar Pekec, and Ronald M. Harstad (1995), "Computationally Manageable Combinatorial Auctions," Working Paper, Rutgers University.

Salant, David J. (1995), "Up in the Air: GTE's Experience in the MTA Auctions for PCS Licenses," Working Paper, Charles River Associates, Boston, MA.

Table 1

Final Outcome in Nationwide Narrowband PCS Auction (Round 47)

Frequency Block	License Type (kHz)	Round of Final Bid	Winning Firm	Winning Bid ($M)	Price ($/MHz-pop)
1	50/50	37	PageNet	80.0	3.17
2	50/50	37	PageNet	80.0	3.17
3	50/50	33	McCaw	80.0	3.17
4	50/50	33	McCaw	80.0	3.17
5	50/50	37	Mtel	80.0	3.17
6	50/12.5	24	AirTouch	47.0	2.98
7	50/12.5	25	BellSouth	47.5	3.01
8	50/12.5	24	Mtel	47.5	3.01
10	50	45	PageNet	37.0	2.93
11	50	46	PageMart	38.0	3.01
Total	500/287.5			617.0	3.10

Note: Block 9 was a Pioneer's Preference award to Mtel for $33.3 million.

Table 2

Final Outcome in Regional Narrowband PCS Auction (Round 105)

Freq Block	Type (kHz)	*Winning Bidder by Region*					*Winning Bid ($M) by Region*					Block Total	Premium Over Nationwide Auction
		Northeast	South	Midwest	Central	West	Northeast	South	Midwest	Central	West		
1	50/50	<------PageMart won all regions------>					17.5	18.4	16.8	17.3	22.5	92.6	15.7%
2*	50/50	<------PCS Development won all regions------>					14.9	18.8	17.4	17.1	22.8	90.9	13.7%
3	50/12	<------MobileMedia won all regions------>					9.5	11.8	9.3	8.3	14.9	53.7	13.4%
4	50/12	<------Advanced Wireless won all regions------>					8.9	11.5	10.1	8.8	14.3	53.6	13.3%
5	50/12	AirTouch	InstaCheck	Ameritech	AirTouch	AirTouch	8.7	8.0	9.5	8.3	14.3	48.7	2.9%
6*	50/12	Shearing	Shearing	Shearing	Benbow	Benbow	10.3	11.3	10.3	10.5	10.9	53.2	12.3%
					Region Total		69.7	79.8	73.3	70.3	99.7	392.7	12.4%

Freq Block	Type (kHz)	*Round of Final Bid by Region*					*Price ($/MHz-pop) by Region*					Block Average	Woman/Minority Effective Discount
		Northeast	South	Midwest	Central	West	Northeast	South	Midwest	Central	West		
1	50/50	99	92	101	91	83	3.39	3.55	3.23	3.52	4.72	3.67	
2*	50/50	55	93	102	92	84	2.87	3.62	3.33	3.48	4.77	3.60	1.8%
3	50/12	103	90	98	7	75	2.93	3.64	2.85	2.68	4.98	3.40	
4	50/12	58	89	100	77	73	2.77	3.56	3.09	2.86	4.79	3.40	
5	50/12	42	104	64	78	74	2.69	2.47	2.92	2.69	4.79	3.09	
6*	50/12	56	48	58	45	103	3.17	3.48	3.15	3.41	3.66	3.37	-2.2%
					Region Average		3.00	3.42	3.13	3.17	4.64	3.46	

*Woman/minority bidders get a 40% bidding credit on blocks 2 and 6. All amounts are net of the credit.

Table 3

Final Outcome by Market in MTA Broadband PCS Auction (Round 112)

MTA	Market	Pops (M)	Round A	Round B	Winning Bidder A	Winning Bidder B	Marginal Bidder	Bid ($M) A	Bid ($M) B	Price ($/pop) A	Price ($/pop) B
1	New York	26.4	*	74	Omni	WirelessCo	Alaacr	347.5	442.7	13.16	16.76
2	Los Angeles	19.1	*	82	Cox	PacTel	Alaacr	251.9	493.5	13.16	25.78
3	Chicago	12.1	75	77	AT&T	PrimeCo	WirelessCo	372.8	385.1	30.88	31.90
4	San Francisco	11.9	98	97	WirelessCo	PacTel	AmerPort	206.5	202.2	17.37	17.00
5	Detroit	10.0	36	83	AT&T	WirelessCo	AmerPort	81.2	86.1	8.12	8.61
6	Charlotte	9.8	39	41	AT&T	BellSouth	CCI	66.6	70.9	6.83	7.27
7	Dallas	9.7	100	99	PrimeCo	WirelessCo	Alaacr	87.5	88.4	9.03	9.12
8	Boston	9.5	50	57	AT&T	WirelessCo	Boston	121.7	127.1	12.87	13.44
9	Philadelphia	8.9	36	37	AT&T	PhillieCo	GTE	81.0	85.0	9.07	9.52
10	Washington	7.8	*	77	APC	AT&T	AmerPort	102.3	211.8	13.16	27.23
11	Atlanta	6.9	89	87	AT&T	GTE	Powertel	198.4	184.7	28.58	26.60
12	Minneapolis	6.0	101	88	WirelessCo	AmerPort	Continental	39.7	36.6	6.63	6.11
13	Tampa	5.4	98	85	AmerPort	PrimeCo	WirelessCo	89.8	99.3	16.57	18.33
14	Houston	5.2	110	79	AmerPort	PrimeCo	WirelessCo	83.9	82.7	16.16	15.93
15	Miami	5.1	88	86	WirelessCo	PrimeCo	GTE	131.7	126.0	25.64	24.53
16	Cleveland	4.9	86	87	Ameritech	AT&T	AmerPort	87.0	85.9	17.59	17.36
17	New Orleans	4.9	99	97	WirelessCo	PrimeCo	Powertel	93.9	89.5	19.07	18.17
18	Cincinnati	4.7	87	111	AT&T	GTE	WirelessCo	41.9	42.7	8.89	9.06
19	St. Louis	4.7	91	92	AT&T	WirelessCo	PrimeCo	118.8	114.3	25.48	24.51
20	Milwaukee	4.5	111	98	WirelessCo	PrimeCo	AT&T	85.0	86.0	18.73	18.94
21	Pittsburgh	4.1	79	110	WirelessCo	AmerPort	CCI	28.7	31.7	7.00	7.72
22	Denver	3.9	109	110	WirelessCo	GTE	AmerPort	64.4	64.5	16.60	16.62
23	Richmond	3.8	58	52	AT&T	PrimeCo	CCI	33.7	33.0	8.75	8.59
24	Seattle	3.8	101	100	GTE	WirelessCo	AmerPort	106.4	105.2	27.79	27.48
25	Puerto Rico	3.6	46	47	AT&T	Centen	PrimeCo	56.9	54.7	15.70	15.09
26	Louisville	3.6	104	106	AT&T	WirelessCo	PrimeCo	49.3	46.6	13.85	13.10
27	Phoenix	3.5	95	96	AT&T	WirelessCo	GTE	78.3	75.6	22.32	21.54
28	Memphis	3.5	89	87	Powertel	SWBell	WirelessCo	43.2	43.2	12.46	12.46
29	Birmingham	3.2	84	85	WirelessCo	Powertel	AT&T	35.6	35.3	10.97	10.87
30	Portland	3.1	99	98	Western	WirelessCo	Alaacr	34.2	34.1	11.16	11.16
31	Indianapolis	3.0	80	81	WirelessCo	Ameritech	PrimeCo	70.4	71.1	23.34	23.56
32	Des Moines	3.0	83	81	Western	WirelessCo	MicroLith	22.1	21.0	7.35	7.00
33	San Antonio	3.0	105	104	WirelessCo	PrimeCo	Western	54.4	52.0	18.21	17.39
34	Kansas City	2.9	92	110	WirelessCo	AmerPort	GTE	23.6	23.6	8.11	8.10
35	Buffalo	2.8	81	82	WirelessCo	AT&T	PCSAmer	18.9	19.9	6.80	7.15
36	Salt Lake City	2.6	104	105	Western	WirelessCo	GTE	45.8	46.2	17.82	17.95
37	Jacksonville	2.3	110	108	Powertel	PrimeCo	GTE	46.0	44.5	20.22	19.56
38	Columbus	2.1	101	102	AT&T	AmerPort	WirelessCo	22.3	22.2	10.39	10.34
39	El Paso	2.1	89	88	Western	AT&T	PCSAmer	8.6	8.6	4.08	4.08
40	Little Rock	2.1	99	98	SWBell	WirelessCo	PCSAmer	12.7	12.3	6.21	6.01
41	Oklahoma	1.9	111	81	Western	WirelessCo	PCSAmer	11.1	13.1	5.92	7.00
42	Spokane	1.9	50	86	Poka	WirelessCo	Alaacr	5.7	6.2	3.05	3.32
43	Nashville	1.8	86	87	WirelessCo	AT&T	PrimeCo	16.4	15.8	9.26	8.95
44	Knoxville	1.7	80	82	AT&T	BellSouth	PCSAmer	10.6	11.1	6.18	6.47
45	Omaha	1.7	65	80	AT&T	Cox	CCI	4.6	5.1	2.80	3.06
46	Wichita	1.1	65	27	AT&T	WirelessCo	MicroLith	4.4	4.9	3.91	4.36
47	Honolulu	1.1	108	107	Western	PrimeCo	AmerPort	22.4	21.7	20.18	19.56
48	Tulsa	1.1	106	105	SWBell	WirelessCo	Western	17.6	16.8	16.02	15.32
49	Alaska	0.6	111	89	AmerPort	GCI	Western	1.0	1.7	1.82	3.00
50	Guam	0.2	67	103	Poka	AmerPort	PCSAmer	0.1	0.1	0.61	0.81
51	Amer Samoa	0.0	106	108	SSeas	ComIntl	AmerPort	0.2	0.2	4.57	4.85
	Total	252.6						7,736.0		15.54	

Population is from 1990 US Census.

*In NY, LA, and Washington, band A is Pioneer's Preference award with price based on GATT formula.

Table 4

Final Outcome by Bidder in MTA Broadband PCS Auction (Round 112)

Company	Upfront Payment ($M)	Initial Eligiblity (M pops)	*Number of Markets* Won	Marginal	Total	*Population Coverage (M)* Won	Marginal	Total	Spectrum Won (%)	Winning Bids ($M)	Average Price ($/pop)
WirelessCo	118	197	29	6	35	145	33	178	32	2,110	14.56
AT&T	78	131	21	2	23	107	8	115	24	1,684	15.73
PCS PrimeCo	55	91	11	5	16	57	17	74	13	1,107	19.36
American Portable	20	34	8	8	16	26	43	70	6	289	10.91
Alaacr	33	55		5	5		60	60			
GTE	50	83	4	6	10	19	25	45	4	398	20.56
PacTel	56	93	2		2	31		31	7	696	22.41
Powertel PCS	17	28	3	2	5	9	12	21	2	124	13.85
CCI Data	18	30		4	4		19	19			
Western PCS	10	17	6	3	9	14	5	18	3	144	10.50
BellSouth	7	11	2		2	11		11	3	82	7.15
PCS America	6	10		6	6		11	11			
Boston PCS	6	9		1	1		9	9			
PhillieCo*	5	9	1		1	9		9	2	85	9.52
Ameritech	5	8	2		2	8		8	2	158	19.85
Southwestern Bell	17	29	3		3	7		7	1	73	11.11
Continental	4	6		1	1		6	6			
Micro Lithography	2	3		2	2		4	4			
Centennial Cellular	2	4	1		1	4		4	1	55	15.09
Poka Lambro	2	3	2		2	2		2	0	6	2.84
Cox Cable*	3	6	1		1	2		2	0	5	3.06
GCI	1	2	1		1	1		1	0	2	3.00
Com. International	0	0	1		1	0		0	0	0	4.85
South Seas Satellite	0	0	1		1	0		0	0	0	4.57
Cleveland PCS	3	5									
Century	2	4									
Comcast*	1	2									
Satellite Broadcast	0	1									
Data Link One	0	0									
Windsong	0	0									
Total	522	871	99	51	150	452	253	704	100	7,019	15.54

Note: Sorted by population coverage of markets in which bidder either won or was marginal (last to drop out).

* WirelessCo partner. WirelessCo got an additional 37.5 million in coverage from partnership agreements.

Table 5

Bidder Types and Strategies

	Price Influence* (M pops)	Issues and Strategy
National bidders (all strong)		
WirelessCo**	189	Most vulnerable from value-seeking bidders, since budget constrained. Time attacks in major markets.
AT&T	115	Mostly sincere with deep pockets. Avoid competition with PrimeCo.
PCS PrimeCo	74	Moderate under bidding. Deep pockets. Avoid competition with AT&T. Scale back demands to keep prices low.
Value-seeking bidders		
Moderate		
American Portable	70	Look for value. Get concessions from national bidders or impose costs. Maintain flexibility.
Alaacr	60	Look for value in major markets.
Weak		
CCI Data	19	Look for value. Limited budget.
PCS America	11	Look for value in small markets. Small budget.
Micro Lithography	4	"
Poka Lambro	2	"
Regional bidders		
Strong		
GTE	45	Wait and see. Avoid markets of main interest until late in auction. Budget constrained.
PacTel	31	Sincere bidding in primary markets. Scale back early in secondary markets.
BellSouth	11	Sincere bidding in primary markets.
Ameritech	8	"
Moderate		
Powertel PCS	21	Sincere bidding in primary markets. Modest budget.
Western PCS	18	"
Southwestern Bell	7	"
Weak		
Boston PCS	9	Sincere bidding in single market until too high.
Continental	6	Small budget. Switch to cheap markets if prices too high in primary markets.
Centennial Cellular	4	Sincere bidding in single market.
GCI	1	Wait and see before bidding in primary market.
Com. International	0	Sincere bidding in single market.
South Seas Satellite	0	"
Very weak		
Cleveland PCS		Sincere bidding in single market until too high.
Century		"
Satellite Broadcast		"
Data Link One		"
Windsong		"

*Population coverage of markets in which bidder either won or was marginal (last to drop out).

**Includes partners: PhillieCo, Cox Cable, and Comcast.

Table 6

Bid Withdrawals in MTA Broadband PCS Auction

Round	License	Market	Bidder	Winning Bidder	Bid ($M)	Winning Bid ($M)	Penalty ($M)	My Explanation
18	9 B	Philadelphia	SWBell	PhillieCo	35.7	85.0		Signal drop in eligibility
27	41 B	Oklahoma	Alaacr	WirelessCo	3.1	13.1		Changed mind about bid
66	48 A	Tulsa	Western	SWBell	11.9	17.6		Increase flexibility in next round
81	14 A	Houston	WirelessCo	AmerPort	87.9	83.9		Maintain eligibility
81	15 B	Miami	WirelessCo	PrimeCo	119.4	126.0		Maintain eligibility
82	49 A	Alaska	Western	AmerPort	1.0	1.0		Maintain eligibility
87	12 B	Minneapolis	WirelessCo	AmerPort	38.4	36.6	1.8	Drop double bid used to maintain eligibility
87	41 A	Oklahoma	WirelessCo	Western	13.1	11.1	2.0	Drop double bid used to maintain eligibility
88	28 A	Memphis	WirelessCo	Powertel	45.3	43.2	2.2	Maintain eligibility
97	13 A	Tampa	WirelessCo	AmerPort	94.3	89.8	4.5	Gift for AmerPort to get off San Francisco
97	14 A	Houston	WirelessCo	AmerPort	87.9	83.9		Gift for AmerPort to get off San Francisco
98	38 B	Columbus	WirelessCo	AmerPort	21.1	22.2		Maintain eligibility
102	18 B	Cincinnati	GTE	GTE	42.7	42.7		Increase flexibility in next round
102	33 A	San Antonio	Western	WirelessCo	51.8	54.4		Maintain eligibility
102	49 A	Alaska	AmerPort	AmerPort	1.3	1.0	0.3	Maintain eligibility
104	26 B	Louisville	PrimeCo	WirelessCo	44.4	46.6		Maintain eligibility
108	20 A	Milwaukee	WirelessCo	WirelessCo	85.0	85.0		Increase flexibility in next round
108	41 A	Oklahoma	WirelessCo	Western	10.0	11.1		Reduce penalty
109	14 A	Houston	WirelessCo	AmerPort	87.9	83.9	4.0	Increase flexibility in next round
109	21 B	Pittsburgh	AmerPort	AmerPort	31.7	31.7		Increase flexibility in next round
109	34 B	Kansas City	AmerPort	AmerPort	23.6	23.6		Increase flexibility in next round
						Total	14.8	

Table 8

Comparison of FCC Spectrum Auctions

	FCC Spectrum Auction					
	Narrowband PCS		*Broadband PCS*		*MDS*	*SMR*
	Nationwide	Regional	MTA (A-B)	BTA (C)	BTA	900 MHz
Number of market areas	1	5	51	493	493	51
Number of frequency blocks	10	6	2	1	1	20
Number of licenses	10	30	99	493	493	1020
Total spectrum (MHz)	0.7875	0.45	60	30		
Revenue including pioneer preference ($M)	650	395	7,736	10,219	216	312
Average price ($/MHz-pop)	3.10	3.46	0.52	1.33	NA	NA
Number of bidders	29	28	30	255	155	128
Number of winning bidders	6	9	18	89	67	80
Correlation between upfront payment and spectrum won	78%	83%	93%	64%	63%	80%
Number of rounds	47	105	112	184	181	168
Number of days	5	10	60	84	75	79
Number of bids	385	738	2,268	29,865	15,417	14,931
Bids per license	38.5	24.6	22.9	60.6	31.3	14.6
Switch to stage 2 in round	never	21	12	58	51	17
Switch to stage 3 in round	never	74	65	70	87	37
Percent revenue raised in stage 1	100%	80%	13%	88%	44%	54%
Percent revenue raised in stage 2	0%	14%	52%	6%	22%	10%
Percent revenue raised in stage 3	0%	6%	36%	7%	35%	36%
Initial eligibility ratio	8.8	6.1	1.9	6.7	3.6	2.4
Eligibility ratio at end of stage 1	1.0	3.1	1.9	1.8	1.9	1.8
Eligibility ratio at end of stage 2		1.5	1.5	1.3	1.3	1.4
High bidders at end of stage 1 that eventually win	100%	71%	53%	60%	64%	48%
High bidders at end of stage 2 that eventually win		71%	76%	72%	79%	59%
Correlation between final prices and prices at end of stage 1	100%	65%	32%	87%	66%	58%
Correlation between final prices and prices at end of stage 2		91%	83%	90%	78%	69%
Licenses with final bids at end of stage 1	100%	3%	0%	34%	15%	8%
Licenses with final bids at end of stage 2		29%	19%	57%	42%	18%
Number of bid withdrawals	0	2	21	50	23	64
Bid withdrawal penalties ($M)	0.0	2.1	14.8	147.3	0.1	107.5